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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of:
HENDERSON ET AL.

Serial No. **09/939,517**

Confirmation No. **2428**

Filing Date: **August 24, 2001**

For: **METHOD OF DETECTING FLICKER AND VIDEO CAMERA USING THE METHOD**

TRANSMITTAL OF CERTIFIED PRIORITY DOCUMENT

Director, U.S. Patent and Trademark Office
Washington, D.C. 20231

Sir:

Transmitted herewith is a certified copy of the priority United Kingdom Application No. 0020857.9.

Respectfully submitted,

Michael W. Taylor

MICHAEL W. TAYLOR
Reg. No. 43,182
Allen, Dyer, Doppelt, Milbrath & Gilchrist, P.A.
255 S. Orange Avenue, Suite 1401
Post Office Box 3791
Orlando, Florida 32802
Telephone: 407/841-2330
Fax: 407/841-2343
Attorney for Applicant

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1. Your reference — P26168/TCO/JC

2. Patent application number *(The Patent Office will fill in this part)* — 0020857.9 — 25 AUG 2000

25AUG00 E563425-4 D02884
P01/7700 0.00-0020857.9

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

VLSI Vision Ltd
Aviation House
31 Pinkhill
EDINBURGH
EH12 7BF

Patents ADP number *(if you know it)* — 778793001

If the applicant is a corporate body, give the country/state of its incorporation — United Kingdom

4. Title of the invention — "Method of detecting flicker, and video camera using the Method"

5. Name of your agent *(if you have one)* — Murgitroyd & Company

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

373 Scotland Street
GLASGOW
G5 8QA

Patents ADP number *(if you know it)* — 1198013

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*
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Number of earlier application	Date of filing *(day / month / year)*
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Claim *(s)*	4
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Murgitroyd & Company

Date

24 August 2000

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JOHN COOPER 0141 307 8400

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"Method of detecting flicker, and video camera using the Method"

This invention relates to a method of detecting lighting-induced flicker in a video signal, and to a video camera equipped for carrying out this method.

Artificial lighting derived from alternating-current sources, particularly fluorescent lighting, contains a strong brightness modulation component, or *flicker*, at twice the mains frequency, this factor of 2 arising from the power-relation between instantaneous mains voltage and instantaneous brightness, and from the trigonometric relation $\cos^2(x) = 0.5(1+\cos(2x))$. Commonly encountered flicker frequencies are 100Hz in Europe and 120Hz in USA. Although invisible to the human eye, flicker may be highly visible to image sensors. The problem is most apparent at low exposure values; in the limit, short-time pixel exposure samples this modulation waveform as

reflected from objects in the scene and reproduces it perfectly.

Solid-state sensors fall into two broad categories according to exposure method; full-field, where all pixel elements of the sensor are exposed simultaneously, and rolling window, where all pixel elements in a sensor row are exposed simultaneously, but the onset of exposure is delayed from row to row. Lighting flicker induces a cyclical variation in luminance, known as 'banding'; apparent in the time domain, and, in the case of rolling-window sensors, also in the vertical spatial domain.

In the case of the rolling-window sensors, should the camera and mains be in perfect synchronisation, the modulation pattern will be temporally frozen, appearing as static luminance banding down the image. However the problem is compounded if camera field rates and mains frequency differ by some amount, causing the luminance modulation bands to roll up or down the image. The rate of roll depends mostly on whether the camera is operating *home* or *away*, i.e. nominal frame rate is a close sub-multiple of mains frequency or not. For example, a 50Hz camera operating in the USA is operating away. Roll associated with a camera operating at home is extremely slow, while roll associated with a camera operating away is much faster.

As well as being visibly distracting to the viewer, luminance modulation generates considerable frame-to-frame differences in image streams which could, for example, make the difference between a software video CODEC performing acceptably or not. Thus it is important that a camera system be capable of detecting and cancelling artificial lighting flicker.

Detection of lighting flicker in the spatial domain is difficult in the case of rolling-window exposure sensors, and impossible in the case of full-field exposure sensors. In the former case the difficulty is due to potential strong correlations between expected banding patterns caused by lighting flicker and variations in actual scene luminance.

One object of the present invention is to provide a time-domain technique for detecting and identifying the frequency of flicker, and which is capable of being applied to both full-field exposure sensors and rolling-window exposure sensors.

US Patent 5053871 discloses a still video camera which uses a previewing technique to provide automatic exposure control and flicker detection. The present invention relates to motion video cameras and a concurrent detection technique. US Patent 5272539 discloses a video camera with flicker detection, but in this prior arrangement the detector frame rate is coupled with the video frame rate, which limits its usefulness. The invention in its

various aspects is defined in the claims appended hereto.

An embodiment of the invention will now be described, by way of example only, with reference to the drawings, in which:

Fig.1 is a schematic representation of a photosensitive array used in one form of the present invention;

Fig.2 illustrates a sampling method used in this embodiment;

Fig.3 is a block diagram of the flicker detection method of this embodiment; and

Fig.4 is a block diagram showing use of the method in a video camera.

Referring to Fig.1, a photosensitive array comprises an array of pixels 10. It will be appreciated that Fig.1 is highly schematic, with only a small number of pixels 10 being shown. Additionally, the array comprises one or more (in this embodiment, two) super-pixels 12 and 14. Each of the super-pixels 12,14 differs from the pixels 10 of the main array in two principal ways:

The super-pixel 12,14 is physically large in comparison to the pixels 10 of the main array, in

order to stand a better chance of imaging some part of the scene which contains a flickering light source or reflects such a flickering source. In this example, each super-pixel is one entire column of photosensitive pixel elements 10 which have been electrically commoned.

The super-pixel 12,14 is exposed and sensed in a manner independent from the pixels 10 of the main array. While each line of the main array is sensed at the frame rate dictated by the application, the super-pixel is sensed independently, usually at a rate much higher than the sensor frame rate, in order to produce a suitable sequence of readings in each period of the lighting flicker. A convenient rate at which to sense the super-pixel is the line-rate of the application, usually some hundreds of times faster than the frame-rate.

Separate means must be provided to control the gain of the super-pixel, to ensure its output sample falls within its linear operating range while maximising dynamic range.

The super-pixels may be provided by commoning a column of standard size pixels, as indicated at 20 in Fig.1.

The output of the super-pixel(s) is then operated on by a detection mechanism which will now be described with reference to Figs.2 and 3. The following

description refers to the use of a single super-pixel. The detection mechanism operates *ad infinitum* on successive length-N sequences f(n) of *compound samples*, each compound sample comprising one or more accumulated individual samples s(a) of the super-pixel. Each compound sample is spaced apart by an appropriate interval I, and we refer to interval I as the *compound sampling interval*. The individual super-pixel samples s(a) are accumulated over a fixed number of lines A, less than or equal to interval I and referred to as the *compound sampling aperture*. Such accumulation allows an ensemble reduction of random components contained in each super-pixel reading s(a) at the expense of amplitude reduction of the super-pixel signal at the frequencies of interest, attributable to the roll-off effect of sampling aperture:

$$f(n) = \frac{1}{A}\sum_{a=1}^{A} s(a)$$

Note that in the cases where the desired compound sampling interval I cannot be expressed as an integer multiple of the sensor line-interval , the compound sampling interval can be adjusted on an instantaneous basis so as to average-out to the desired interval over time. The resultant phase jitter is tolerable, as long as the compound sampling aperture remains constant. Figure 2 illustrates the composition of the sequence f(n) for N=3.

One example of a detection mechanism takes the form of a bandpass filter, tuned to the nominal frequency of flicker. If the compound sample-rate of the super-pixel is chosen as a multiple of the nominal flicker frequency, a simple detector might use the fundamental output component F(1) of a radix-N butterfly, or N-rotor. This circuit performs complex correlation with the fundamental Nth-root of unity, to produce the instantaneous measure of complex flicker energy **E**:

$$\mathbf{E} = \mathbf{F}(1) = \sum_{n=0}^{N-1} f(n) e^{-2\pi\frac{n}{N}}$$

While radix-2 is the simplest butterfly, its response is phase-dependent and therefore unreliable. As N increases, so does hardware complexity, and the smaller the compound sampling interval and potential aperture. We have found that N=3 or 4 yields the most efficient and effective solutions.

These instantaneous complex flicker energy readings **E′** must be averaged over time in some manner to produce a longer-term estimate **E′** of flicker energy. One example of an averaging mechanism is the first-order autoregressive filter, or leaky-integrator, whose ability to track phase drift may be traded against noise-immunity by means of its system time-constant μ, updating long-term average **E′** with instantaneous measure **E**:

$$\mathbf{E}' = \mathbf{E}\mu + \mathbf{E}' \ (1 - \mu)$$

The process of magnitude extraction affords some protection against phase drift, an inevitable consequence of short- or long-term differences between actual and nominal flicker frequencies. The final flicker detection decision should be based on the magnitude or modulus of long-term average E′, for example if T is some programmable or pre-defined threshold, then the boolean decision variable d can be defined:

$$\mathbf{d = |E'| > T}$$

Note that the compound sampling interval may be chosen so as to undersample the flicker signal, relying on the folding or aliasing effect to detect harmonics of a notional sub-harmonic of flicker. While this method allows longer exposure times or compound sampling apertures, it is less able to track flicker frequencies differing from the nominal, as the error in instantaneous angular frequency is greater than that of the fundamental case for a given difference between actual and nominal flicker frequencies.

Fig.4 shows the foregoing method used in a flicker-detecting video camera.

The main sensor array 10′ has its exposure setting controlled by either the output of an automatic exposure control circuit 18 of known type, or by a flicker-free exposure setting. The choice between

these two is controlled by the Boolean operator and as derived above.

The actual correction of lighting flicker, once detected and identified in frequency, is straightforward.

To expand on the sampling analogy, it is well known that increasing a sampling aperture away from the therotical perfect sampling (convolution with a dirac-delta pulse train) causes a roll-off of frequency response which obeys the equally well-known sin(x)/x or *sinc* function. If the exposure window is considered as a sampling aperture, then those temporal frequencies present in the scene whose period coincides with the temporal duration of the exposure window, or harmonics of such frequencies, will be rendered invisible, as they coincide with nulls in the sinc function. The simple expedient of setting exposure period to the inverse of a suspected mains flicker frequency or one of its harmonics will then provide effective banding removal.

A weakness of this scheme can arise under bright lighting conditions. Here the sinc function approaches the origin and no sinc-function null can be found which corresponds to a desirable exposure setting. Without recourse to additional exposure control mechanisms such as LCD shutter or mechanical iris, a compromise must be sought between acceptable banding and acceptable exposure setting.

The invention thus provides a technique for detection and frequency identification of flicker which operates in the time domain and which is applicable to both full-field exposure sensors and to rolling-window exposure sensors.

Modifications and improvements may be made to the foregoing embodiment within the scope of the invention.

Claims

1. A method of detecting lighting flicker in the output of a video imaging device, the video imaging device having a main picture area divided into pixels and producing successive images at a frame rate; the method comprising producing a series of signals from an additional picture area adjacent said main picture area, the additional picture area having a size substantially larger than a pixel, each of said signals being a function of light incident on the additional picture area in a time period substantially shorter than that of the frame rate; accumulating predetermined numbers of said signals to form a series of compound samples; and filtering the compound samples to detect components indicative of flicker.

2. The method of Claim 1, in which said time period is equivalent to the line rate of the main picture area.

3. The method of Claim 1 or 2, in which said signals are derived from a plurality of additional picture areas.

4. The method of any preceding claim, in which said filtering is effected by a bandpass filter tuned to the nominal frequency of the flicker.

5. The method of any of Claims 1 to 3, in which said compound samples are formed at a sample rate which is a multiple of the nominal flicker frequency, and said filtering is effected by taking the fundamental output component of a radix-N butterfly.

6. The method of Claim 5, in which N is 3 or 4.

7. The method of Claim 5 or Claim 6, in which said fundamental output component represents instantaneous complex flicker energy E, and in which E is averaged over time to produce a longer-term estimate E′ of flicker energy.

8. The method of Claim 7, in which E′ is produced according to the relationship

$$\mathbf{E' = E\mu + E' \ (1 - \mu)}$$

where μ is a time constant.

9. The method of Claim 7 or Claim 8, further comprising deriving the modulus of E′ and comparing this with a predetermined threshold T to give a final estimation of flicker being present if $|E'| > T$.

10. A method of ameliorating lighting flicker in the output of a video imaging device; the method comprising detecting flicker by the method of any preceding claim and, during any time when flicker is detected, operating the main picture area of the

imaging device at an exposure setting selected to eliminate or minimise flicker.

11. The method of Claim 10, in which said exposure setting comprises an exposure period which is the inverse of the flicker frequency or a harmonic thereof.

12. A flicker-detecting video camera comprising a video imaging device having a main picture area divided into pixels and producing successive images at a frame rate, and at least one additional picture area adjacent said main picture area and having a size substantially larger than a pixel, the additional picture area or areas being arranged to produce a series of signals each of which is a function of light incident on the additional picture area(s) in a time period substantially shorter than that of the frame rate; means for accumulating predetermined numbers of said signals to form a series of compound samples; and filter means for filtering the compound samples to detect components indicative of flicker.

13. The video camera of Claim 12, in which the or each additional picture area is a strip down one side of the main picture area.

14. The video camera of Claim 13, in which the or each additional picture area is formed by connecting a column of pixels in common.

15. The video camera of any of Claims 12 to 14, including gain control means for the additional picture area(s) independent of the gain control of the main picture area.

16. The video camera of any of Claims 12 to 15, which the filter means comprises a radix-N butterfly.

17. The video camera of Claim 16, further including an averaging circuit connected to the output of the radix-N butterfly.

18. The video camera of Claim 17, in which the averaging circuit is a first-order autoregressive filter.

19. The video camera of any of Claims 12 to 18, including an automatic exposure control circuit, a second exposure control circuit setting an exposure period which is the inverse of a known or anticipated flicker frequency or a harmonic thereof, and control means connecting the automatic exposure control circuit or the second exposure control circuit selectively to control exposure of the main picture area in dependence on the output of said filter means.

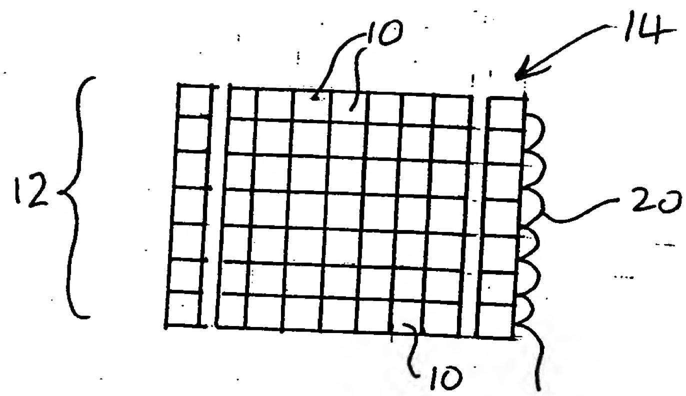

FIG. 1

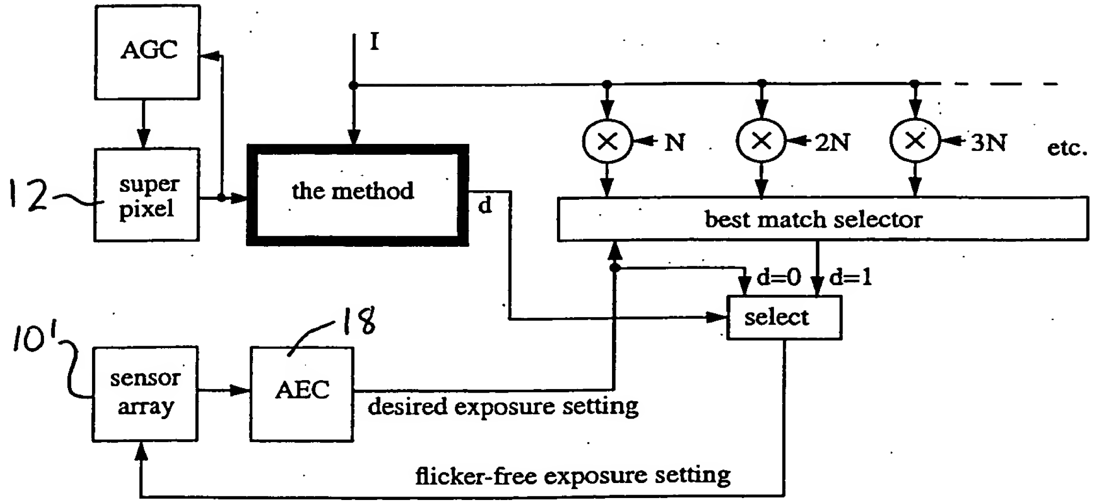

Figure 4: use of the method in a flicker-detecting video camera

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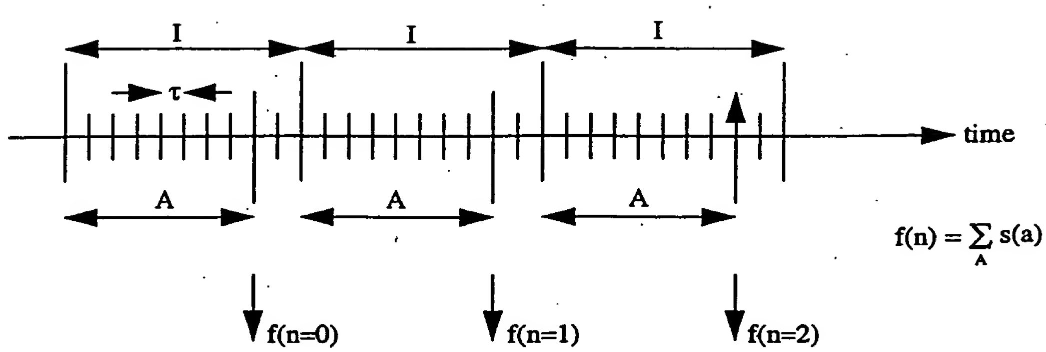

Figure 2: compound sampling interval and aperture

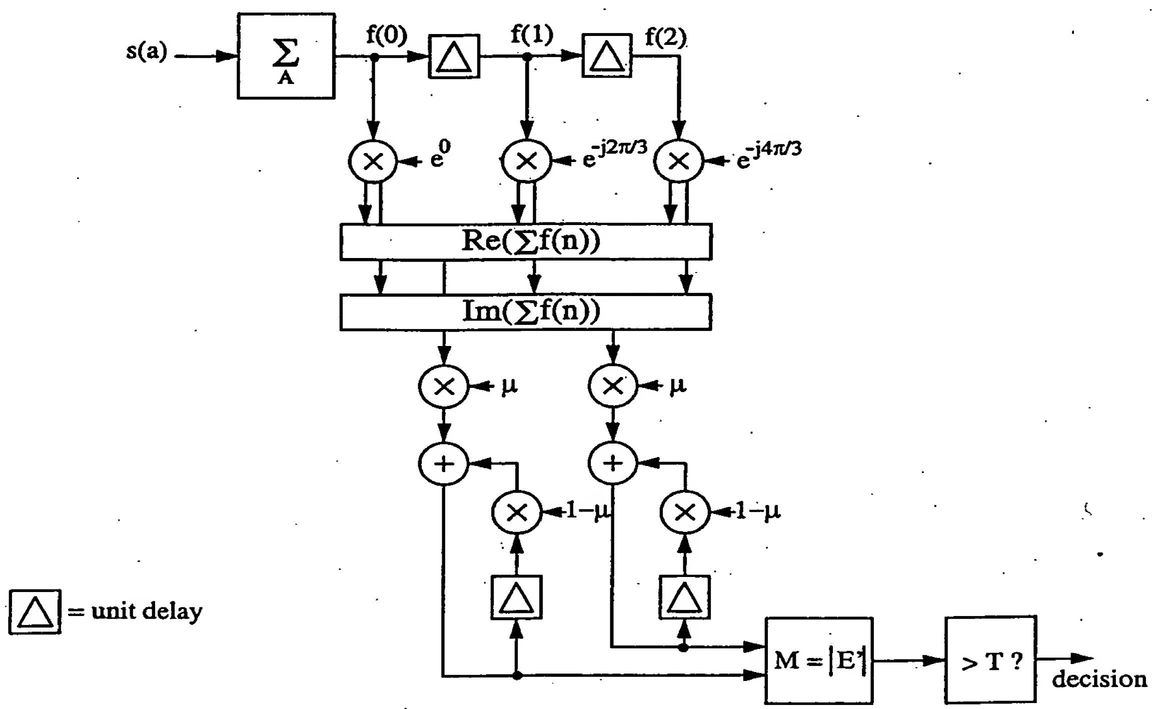

Figure 3: block diagram of flicker detection method